WORCESTER POLYTECHNIC INSTITUTE
ROBOTICS ENGINEERING PROGRAM

Demining Autonomous System

User Guide

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1.0 Introduction

The purpose of this document is to inform subsequent users of the WPI Demining MQP project, whether in a professional or academic setting. There were many specific things that needed to be done with this system that were discovered over time and were not intuitive, so this document is meant to highlight those and ensure that future users would be able to effectively use and implement the entire system.

This project was created through the WPI MQP system under Professor Craig Putnam to address the humanitarian crisis that is safe landmine removal. In many countries around the world, their means for landmine detection is extremely dangerous, using people or animals to find and remove said landmines. With this project, the two part system is meant to autonomously detect and detonate PMN-1 landmines with limited human interaction.

This project utilized two main systems. First, the rover is an A100 Husky that has its navigation system run through ROS nodes. The metal detecting system that is set up on the front of the Husky is run by an Arduino microcontroller The drone is a DJI S1000 system that is run with a Teensy PLC and some subsystems run off an Arduino PLC.

This guide has four main sections that are outlined below:

- Overview - which describes the basic operations of each component and setting it up
- System Operations - which describes how to run the system
- Troubleshooting - outlines common issues with each component and how to fix/avoid them
- System developers - which explains how to access code and software and things that need to be fixed

2.0 Overview of System Parts

2.1 Base Station

The base station box contains five separate items: The laptop, the laptop charger, the differential GPS (and attachment cable), the wireless link (and attachment cable), and an XBee-based remote controller. The two external devices should be plugged into the two USB-A ports on the laptop before the start of a mission. The application can be found as a link on the desktop called "Demining Autonomous Systems", that when clicked, opens to the following screen:

Demining Autonomous System

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Start Demining

About

Figure 1 Application Welcome Screen

On this screen there is an "About" button that explains the background work for the application but is not necessary knowledge for the mission. To start the mission, simply click "Start Demining". Below is an example page of the application:

Figure 2 Application in Use

Some of the other buttons you will see through the applicationinclude the "Abort Mission" button. The "Abort Mission" button can be found on any page where a robot is performing a task. If something goes wrong or you would like to end the mission for whatever reason, you can click the "Abort Mission" button and it will bring all systems home and end all tasks.

2.2 Drone

Managing the Batteries

There is one battery on the drone, and it is located under the center frame, on a platform that clips into the frame of the drone. To remove the drone's battery:

1. Reach below the battery to the metal clip; it should be on the side of the battery where the wires come out.
2. Pinch this clip and slowly slide the battery horizontally; the entire battery tray should slide from its spot within the drone.
3. To remove the battery from the tray, just take off the Velcro surrounding the battery and it should be easy to remove.
4. From here, the battery can easily be charged to prepare for a mission.

Figure 3 Battery Mounting Point

To put the battery back into the drone:

1. Ensure the battery is at 24V (by looking at the voltage on the charging station) before putting the battery back in the drone.
2. Attach the battery to the battery tray with the Velcro; the wires should be on the same side of the tray as the silver clip.
3. Slide the battery tray into its position underneath the main plate of the drone; you should see two rails that the tray sits on top of and a notch in the crossbar that the clip attaches to
4. Pinch the clip and slide the clip over the crossbar, then release it to lock the battery in place. To ensure the battery is secure, lightly tug at the battery tray; if the clip is properly secured the tray should not move.

Dropping Mechanism

The dropping mechanism is closed by four locking pins. To reload the mechanism, remove the four pins (while supporting the rest of the bottom) and lower the cylinder. The figure below shows where the pins are located in regard to the dropping mechanism:
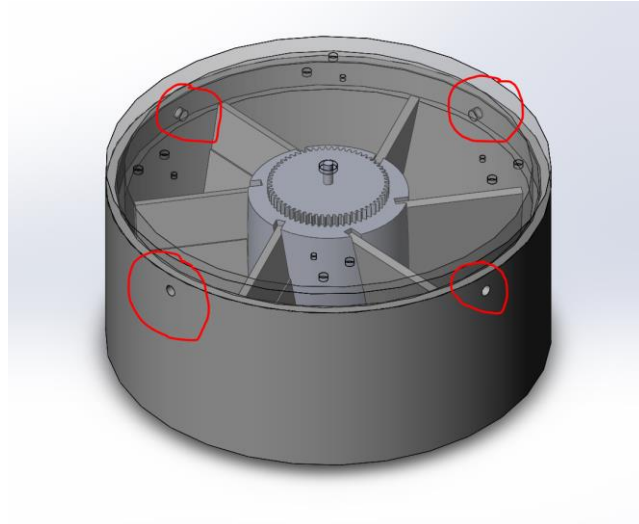
3

Figure 4 Dropping Mechanism Schematic

Once this is detached, there should be six slots to place balloons into. You can place the payloads into each slot, then return the cover to the top of the dropping mechanism and put the pins back into place. Before attaching the dropping mechanism back onto the drone, ensure that the slots can still slide easily and that the top and bottom pieces of the dropping mechanism are securely attached to one another.

Common Lights and Sounds

Generally, there are three main light combinations you will see from the LED on the Pixawk: blue flashing, green flashing, green solid, and yellow flashing.

- Blue flashing means the drone is disarmed and does not have a GPS fix.
- Flashing green means the drone has a GPS lock but is still disarmed.
- Solid green means the drone is armed and ready to fly.
- Flashing yellow means the drone failed its pre-arm checklist (multiple reasons this could happen).

More info on these can be found on the Ardupilot website (Ardupilot LED Codes). Similarly, there are also a wide variety of sounds the drone may make. More information on what each noise means can also be found on the Ardupilot website (Ardupilot Sound Codes).

Drone Anatomy
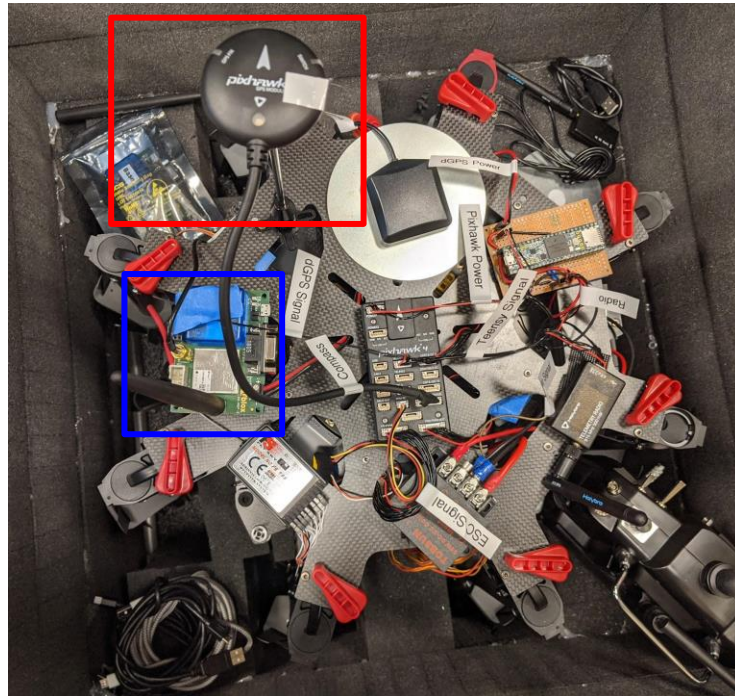
Figure 5 Top Down View of the Drone

Error! Reference source not found. shows a top down view of the drone. In this image, there are two items highlighted that need to be set up right before a GPS signal can be achieved. The item in the blue box is the dGPS module, and it needs the black antenna screwed into the board. In the red box is our external compass, and that needs to be tilted upright then screwed into its base to stay upright.

Figure 6 Drone Control System

Figure 6 highlights the flight control architecture of the drone. The Pixhawk 4 flight controller is outlined in green. This module handles low-level control of the drone, keeping it stable and executing basic maneuvers like taking off, landing, or flying to a point. The blue box highlights the Teensy 3.5 microcontroller. This device handles high-level control: telling the Pixhawk where, when, and how to fly; communicating with the base station; and controlling the dropping mechanism.

Figure 7 Schematic of the Whole Drone

This picture shows the side view of the drone. Here is a labeled list of the common names for the important parts that you will hear used a lot:

Table 1 Labels for Drone Schematic

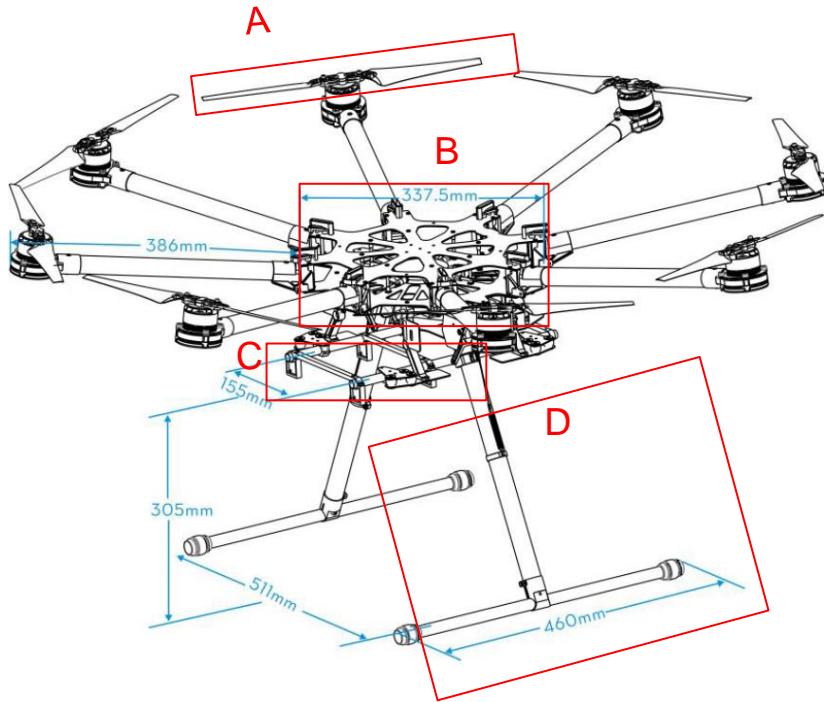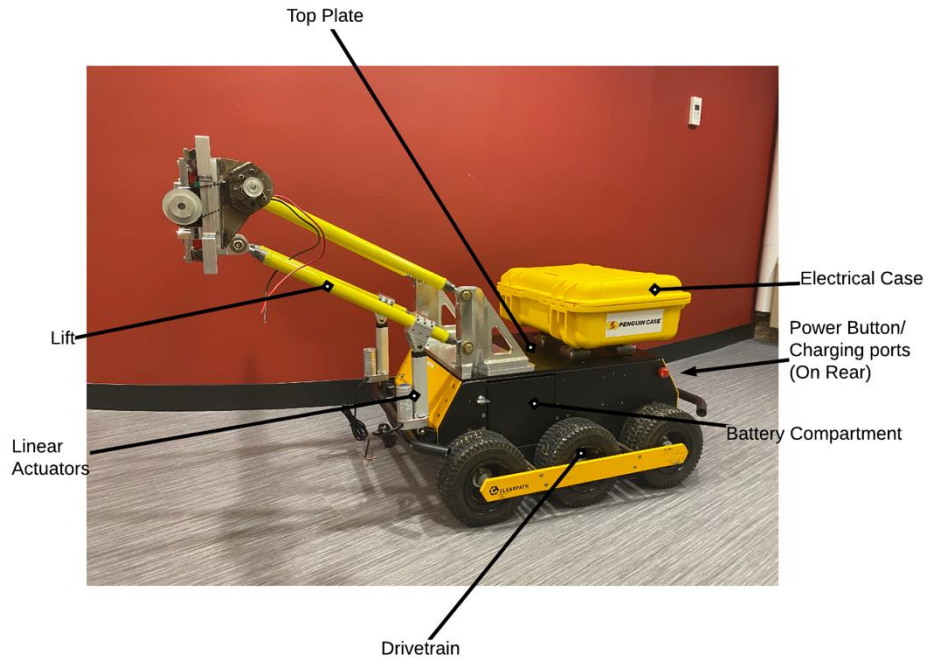| A	Props
B	Center Plate
C	Battery Tray
D	Landing Skid

2.3 Rover

Figure 8 Labeled Essential Terms on Rover

There are a few necessities to cover when preparing the rover for operation, especially during the first attempt at doing so.

Charging the Battery

The rover is powered by two 12-Volt car batteries on the left and right side of the chassis. The two batteries are removable, if you see the need to remove them, though they can also be charged from the rear of the rover without having to access the interior of the rover at all. There are two plugs on the rear of the rover near the power button that will accept special charging inputs. The chargers for these can be plugged into any normal American wall outlet. If, however, you do need access to the independent batteries, or would like to replace them, etc. there are two locking mechanisms on either side of the rover that keep the battery doors locked in place so that they do not open up during operation of the rover. When replacing the batteries or removing them for any reason, you should remember to place the battery terminal side down so that the wiring from the battery does not collide with any parts of the chassis when closing the battery doors. Ensure that the system is entirely powered down before charging or plugging anything in, as all the electronics are also powered directly from the 12V batteries. Please note that the system will not power on, unless the two battery side-doors are closed.

Powering the Rover

There is a power on button in the rear of the rover, near the battery charging ports. The rover is designed to fully power up from just the one power button, but there is a failsafe switch inside the electronics case as well which is used to turn power off to the more important electronics of the system as a whole. This can be activated separately in order to ensure there are no power surges or anything dangerous for the electronics upon start up.

Another important thing to note, especially while working on the rover and potentially modifying it, is the location of the power routing board and the fuses leading away from the power supplies. Both of these can be found under the top plate of the rover. There are several fuses, protecting the different voltage level outputs from the board. They are standard issue and replaceable with ease. However, the routing board cannot supply sufficient current to run the CIM motors, so the power supply for the CIM motors is taken directly from the battery terminals and passed up through the top plate, bypassing the board altogether.

Rover-Computer Interfacing

To access the internal computer of the Husky A100 and issue commands or reconfigure onboard settings, an SSH tunnel is used. Connect to the wireless network output by the rover on startup, look up the robot's IP with `ifconfig` (on Linux), and connect with the password "clearpath". More detailed instructions on using SSH in Linux and how to interface with the Husky after connection can be found in the links in Table 2.

Table 2 Useful Links for Rover Interfacing

Linux SSH Tutorial	https://www.ssh.com/ssh/command/#ssh-command-in-linux
Husky ROS Tutorial	http://wiki.ros.org/husky_control/Tutorials/Interfacing%20with%20Husky

Useful Links

The Husky came with a set of default settings and hardware that have since been adapted with custom fitted and manufactured. This means that along the way there are several products from companies outside of those two categories as well. Table 3 lists the important parts on the rover, and where to find more information regarding the operation and troubleshooting of said parts.

Table 3 Useful Links for Rover Parts

Part	Link
12V Motor Controllers	https://www.robotshop.com/media/files/pdf2/mdds10_users_manual.pdf
Teensy	https://cdn.sparkfun.com/assets/9/0/3/b/e/K64P144M120SF5RM.pdf
CIM Motor	https://www.vexrobotics.com/217-2000.html#Other_Info
Linear Actuators	http://shorturl.at/BST58
Encoders	https://www.cuidevices.com/product/resource/amt10-v.pdf

3.0 System Operation

3.1 Pre-Mission Preparation

Charging the Batteries

Prior to setting up the system for demining operations, ensure that the drone battery and at least two rover batteries are fully charged. If you are planning to have the rover search an extremely large area, it may be beneficial to bring extra batteries to swap out during the mission.

Please ensure the laptop on the base station is fully charged before starting a mission, and ideally, if you can have a power source near your base station location on extended missions, it will be easier to charge all the batteries.

Assembling the Projectiles

Projectiles that will be dropped from the drone must be prepared or acquired. To make the projectiles you need the following:

- Water balloons (ideally the biodegradable kind)
- A water pump with enough pressure to fill the balloons with water
- A scale to weigh the balloons

To make the projectiles, you need to do the following:

1. Fill the water balloon using your water source until it is about the size of the palm of your hand.
2. Use the scale to test that the water balloon is at least 0.5lb and ensure than the water balloon is no more than 2.5 inches in diameter
3. Before tying the balloon closed, ensure it can fit through the lower hole on the dropping mechanism (most balloons at 0.5lbs should fit through with ease)
4. Once you know the balloon is of the correct weight and size, tie the balloon closed and tape the bit sticking up above the knot flat against the balloon. Balloons should be roughly the size seen in the image below

Figure 9 Proper Water Balloon Size

If you are unable to use water balloons, other items such as bags of dirt or sand can also be used. As long as the payload weighs at least 0.5 lbs., it can fit through the dropping mechanism, and will not cause excess shrapnel upon detonating the landmine (such as rocks, bags of bolts, etc.) then you should safely be able to use these substitutions. Note that some payload shapes can alter drop trajectory due to aerodynamics. If custom payloads are used, ensure that their exterior surfaces are smooth, and their internal density is evenly distributed to help ensure accurate dropping trajectories.

3.2 System Setup

Base Station Setup

When you set up the base station, ensure you are at least 50 meters from the outer edge of the minefield (the landmines have a blast radius of approximately 35 meters, and we don't want you to put yourself in danger). Here is how you set up the base station:

1. Open the container; you will find a laptop, a wireless connector, and a dGPS module. Turn on the laptop and plug the two extra devices into the two USB ports on the laptop.
2. Once the laptop turns on, click on the application on the desktop called "Demining Autonomous System". This should take a few moments to open.
3. The application you have just opened will guide you through the setup of the rover and drone. If you have questions, there are "Help" buttons on each page of the application.
4. To begin the mission, click the "Start" button in the application.

Drone Setup

The "Demining Autonomous System" Application will walk you through the setup of the machine but here are the items you need to have on hand before you begin:

- The Drone (in its case)
- At least 1 Battery (fully charged)

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- The dropping mechanism
- At least six projectiles (bring more if your minefield is large or densely packed)

Rover Setup

The "Demining Autonomous System" Application will walk you through the setup of the machine but here are the items you need to have on hand before you begin:

- The Rover
- At least 2 Batteries (fully charged)
- XBee controller (optional)

3.3 System Operation

Once the mission has been initialized through the "Start" button in the DAS application, the software will provide alerts and instructions to ensure completion of the mission. If an alert is issued by the software, instructions will be displayed onscreen and the mission will halt until the alert is cleared. Possible alerts from the software include:

- Drone bay empty: refill payloads
- Low battery on either the drone or the rover
- The rover has become trapped in terrain
- Radio connection to the drone or rover has been lost
- GPS signal quality issues

In the event the robot gets stuck in terrain or pathfinding, the remote control unit can be powered on and manual control can be assumed to 'rescue' the robot.

Once the mission is completed, the results of the mission will display on the base station. At this point, the rover and drone will return to the base station and await further instruction.

3.4 Post-Mission Cleanup

Base Station

Once the mission is complete and both robots are back at the base station, you can close out of the Demining Autonomous Systems Application and begin to clean up the base station:

1. Close the Demining Autonomous Systems application and ensure that all systems have stopped running.
2. Power down the laptop and unplug the external devices.
3. Wrap the wires from the external devices and place them into the slots in the carrying case.
4. Close the laptop and close and snap shut the case.

Drone

Before you start trying to pack up the drone after a mission, make sure the drone is disarmed (you can tell it is disarmed when the LED on the Pixhawk is blinking). If the drone is still armed, do NOT go near it as it could easily try and take off again; stay at least 10 feet away from it until the drone is disarmed. Once the drone has safely disarmed:

1. Unplug the battery cable (you should see all lights and sounds from the drone stop)
2. Remove the dropping mechanism (with the pins) and remove any remaining payloads from the bay. Put the cover back on the dropping mechanism and set aside.
3. Use the foam inserts to secure the props to the drone arm. The props should be placed together and slide into the slit on the foam, and the crescent shaped cutout should attach to the arm of the drone.
4. Unclip the drone arms from their flying position by twisting the large red clip at the base of each arm. The arms should bend in smoothly.
5. Unscrew the dGPS antenna and external compass from the top of the drone and place them either in the bottom of the case or lightly tucked under wires on the top of the drone.
6. Carefully lift the drone and place it into the carrying case. The landing skids should fit into the slits on either side of the case and all of the arms should fit into the case without pushing against the sides.
7. Place the dropping mechanism into the case alongside the drone.

Rover

Ideally the rover will be brought to the site on a wheeled device (dolly, pickup truck, cart, etc.) or the minefield is close enough to the storing facility where you can just drive the rover to the site. In these scenarios, you can switch the rover into teleoperated control and drive it as far as possible, before using safe lifting techniques (or a ramp) to move it onto a device that will move it the rest of the way. Once the rover is either back to its storage location or on a device that can bring it there, you can do the following steps to power down and pack up the rover:

1. Ensure the four bar is high enough off the ground where it will not drag along the ground
2. Power down the rover and remove the batteries from the side compartments

4.0 Troubleshooting and Maintenance

4.1 Common System Issues

Issue: The dGPS module is having trouble getting a fix

Solution: All dGPS modules need to have "clear skies" to get an accurate fix on their location. Ensure each dGPS module is the highest sensor in the area with nothing covering it. The system also can't be run indoors or on overly cloudy days. If you couldn't see an airplane fly above you, then the dGPS couldn't "see" the satellites above it. You can also decrease the accuracy of the base station's survey-in to see if it is getting no signal or just a weaker signal (if there is any signal at all it should connect with 2 meters accuracy). At the end of the day, the base station's fix does not need to be extremely accurate since the drone and rover use a relative position to the base station for their operation. All they need is a strong connection to the base station.

4.2 Common Drone Issues

Issue: The drone won't arm because of GPS

Solution: Before the Drone and Rover can get a GPS fix, the Base Station needs to complete its survey-in and have an accurate GPS fix on its own location. Once the Base Station has a fix, then it can be set up to communicate its location with the Drone which will in time allow it to arm.

Issue: The drone is beeping, and I don't know what is happening

Solution: Refer to the drone sounds guide ([Link](#)) and see if any of the sounds match what you are hearing. Generally, you should hear beeps when it arms and disarms and before it takes off for a mission, and those are expected and meant to alert you to what is happening.

4.3 Rover Maintenance

The linear rails and ballscrew are potential high-wear components. The linear rails are equipped with rubber seals to prevent ingress of dirt, water and other corrosive materials, but they are not perfect. The ballscrew does not have the same level of protection, and is susceptible to damage and wear if not properly maintained. One of the key protections these components have is their grease lubrication. Grease forms a thin film between the rolling elements, and prevents wear due to friction. It also flushes out some contaminants when new grease is forced into the ballnut and bearing blocks. There are five total grease nipples on the robot, one on each of the four linear bearing blocks, and one on the ballnut. You must take off the plate attached to the four blocks to access all of them with ease. To grease them, you will need a grease gun – you cannot just smear grease on these components as it will be wiped away by the seals. The grease gun clips onto the nipples and you should pump just a few times – when the pressure builds up you should feel it, and this is the indicator that grease is actually making it into the component. If the grease gun won't unclip from the nipple, I find that unscrewing the hose slightly releases the pressure and lets you remove it. Warning – it is possible to over-grease these components and damage them. They were greased when they were installed and this should last quite a while, so they should only need more grease if they stop moving smoothly, or the robot was exposed to rain. We used a basic lithium grease – specifically the grease gun from the Higgins machine shop labeled "TM". Ideally you would use this exact grease gun – mixing different greases may cause trouble.

The other moving components such as the Heim joints are a little trickier. They are lightly oiled from the manufacturer, and have no grease nipples. They should need no maintenance as long as they do not begin to rust, and aren't exposed to fine grit. If they seem to stick, you can oil them with pretty much anything. They are also fairly cheap, and can just be replaced if they go bad. Caution – half of the joints are a left-hand thread. Do not attempt to force a Heim joint if it won't thread in correctly – check to make sure it is the correct thread type.

Tire pressure is a key factor in drivetrain performance, and even tire wear. This is a tough balance to maintain – you want to have grip to be able to drive, but too much grip makes the robot struggle to turn. We regularly check tire pressure and inflate to the recommended pressure, which can found on the side of the tires. However, they can be

selectively inflated to change driving characteristics. For example, the front two tires can be inflated to the maximum pressure, and the rear two can be deflated quite a bit to shrink their diameter. As the robot is fairly front-heavy, it will tend to pivot around the front wheels, and making the front wheels the largest accentuates this characteristic. The rear wheels will tend to drag when the robot pivots around the front wheels, so by deflating them you can actually minimize the drag they create – but if the robot tips back due to terrain, they are still available to perform their job of supporting the robot and providing tractive force.

Battery care is critical to making your batteries last as long as possible. Ideally, the batteries should stay topped up all the time. The provided chargers are capable of "float charging" the batteries, safely keeping them topped up to their maximum capacity, only providing power when they begin to self-discharge. Lead acid batteries can be damaged by sitting at their fully discharged state for too long. They are an older technology, and over time their performance will degrade.

5.0 For System Developers

5.1 Accessing Software

All the software to run the system can be found on GitHub. Below are the links to the various GitHub repositories used:

Rover (ROS) Software: https://github.com/avanosten/demining_19_20_rover_ros

This repository contains the ROS package that runs on the rover's computer. It handles (or should eventually handle) driving of the rover, path planning, navigation, maintenance of the map, and communication with the Teensy 3.5 microcontroller which handles low-level hardware (see next repository). Everything is written in Python 2, to be used with ROS Kinetic on Ubuntu 16.04. None of this code has ever been tested on the real hardware, as it was developed after physical access was lost.

Rover (Teensy) Software: https://github.com/16jcmckenna/Demining-Rover-MQP-2019-20

This repository contains C++ code to run on the Teensy 3.5 microcontroller on the rover. It handles (or should eventually handle):

- Control of the slider mechanism motor and its feedback (encoder and limit switches)
- Control of the 4-bar linear actuators (and their encoders)
- Interfacing of the ultrasonic sensors on the sensor head
- Control of the sensor head orientation servos
- Input from the metal detector via the Arduino Uno

As necessary, information should be passed to the ROS code via a USB connection to the rover computer. Currently, the repository contains limited code for basic setup and reading ultrasonic sensors. Additionally, it contains a modified and reduced implementation of the protocol used for communication between the drone and the base station. It was originally intended that this protocol would be used for USB communication between the rover Teensy and the rover computer, but this may be an overcomplicated solution to a relatively simple

problem. All code in this repository should be compiled using the "Teensy Loader" add-on to the Arduino IDE.

Drone Software: https://github.com/avanosten/Demining-Drone-MQP-2019-20

This repository contains all of the C++ code that runs on the drone's Teensy 3.5 microcontroller. This handles communication with the base station, setup of the drone's hardware systems, communication with the Pixhawk (using the Mavlink C library), and general coordination of the flight plan. This code is finished and tested, with the exception of a necessary minor addition to actuate the dropping mechanism. For documentation of the drone's hardware setup, the communication protocol between the drone and the base station, and the drone's flight plan, see the 2019-20 MQP report.

Base Station Software: contact ellie@thefoltans.us At the time of this writing, this repository contains two unmerged branches in addition to the master branch. The "edfoltan_UI" branch contains code in Java for the user interface. The "avanosten_DroneComms" branch contains the C++ code that must be run on the base station to communicate with and control the drone. Currently, this code is a stand-alone module, but it should eventually be reworked into a ROS node to communicate with the UI and rover. It will need some expansion to take mine locations from the broader system, and coordinate actions with the UI. This code can be compiled using the "make" command. Note: the "DroneComms" code is system-specific due to USB communication with the wireless module and, as-written, must be run on an Ubuntu machine. Further, testing should be performed at time of implementation to confirm the proper set up of the Google API for selection of minefield boundaries, and it's integration with the ROS and physical solutions.

System GrabCAD: contact kcehlers@wpi.edu

The GrabCAD for the Demining Autonomous System currently houses the Rover's mechanical CAD models for both the 2019 and 2020 MQP Teams. It also includes the dropping mechanism CAD for the 2020 Rover design. The 2020 MQP team implemented their Rover CAD designs in Solidworks 2017 and their Drone CAD designs in Solidworks 2016. This allowed for full utilization of GrabCAD functionality – if files are opened in any SolidWorks versions later than 2017 and saved/uploaded to GrabCAD, this disables the online model viewer and ability to visually display changes between model revisions. There is no way to correctly roll back files to older versions of SolidWorks aside from manually re-creating the models.

5.2 Known Bugs

System

Drone
● Note the PID gains in the Pixhawk firmware

- On the last flight for the 2019-20 team, we had reduced the P gain slightly because the takeoffs were a bit unstable. This correction did not seem to fix the issue, so further tuning is likely necessary
- Some assembly required

Rover

- The XBee controller's receiver still needs to be integrated into the rest of the rover's drive system. Recommended setup is to use an interrupt pin on the Teensy to simply pause autonomous operations when the receiver is actively publishing ROS commands.

- Though never verified in the physical system, the 2020 MQP Team anticipated that the Rover would have difficulty driving when turning based on observations of previous iterations of the project. Any drivetrain related problem is most likely due to limited motor power and torque, or the capabilities of the built-in motor controllers on-board the Rover. Possible solutions that the 2020 MQP team discussed included designing and fabricating custom gearboxes for the Husky drivetrain.

5.3 Essential Fixes Before First Mission

System

1. Buy the case for the base station laptop
2. Finish the software for the backend of the base station
3. In lab and field tests, confirm the proper set up of the Google API for selection of minefield boundaries, and the accuracy of it's retrieval and storage of selected GPS coordinates.

Drone

1. Make the bottom plate or buy a new one
2. Buy a new battery
3. Re-assemble the drone
   a. Drone Assembly Guide
      https://drive.google.com/drive/folders/17H28HVGoGz95OH-FoB1_y4uJMjet3a_J?usp=sharing
4. Make sure you have examined the drone code and drone-related base station code, and know what the drone should do
   a. Things to look for/update:
      i. PID Tuning
      ii. Compass Calibration
5. Pre-Flight Check:
   a. Make sure motors are all spinning in the appropriate directions, and the Pixhawk knows which one is which

  b. Make sure props are in good condition, and that clockwise props are on clockwise motors and vice-versa

Rover

1. Finish wiring of the rover based on the wiring diagram provided in the final report
2. Replace the long bolt near the encoders at the base of the lower links of the four-bar. The current bolt is too long and will collide with the encoder PCB if the four-bar is moved. On this topic: **<u>do not move the four-bar up or down until this fix has been made.</u>**

In order to continue development of the rover code, the rover's differential GPS module must be set up appropriately. It should be configured identically to the drone's dGPS module, so the appropriate settings can be seen by looking at that board's configuration. Note: to satisfy the drone's flight controller, the baud rate used by the dGPS boards was increased from 19,200 to 38,400 baud (this is the data-rate of the board's serial output). To facilitate this, the baud-rate of the dGPS wireless links was raised to 38,400 baud, and the air-rate to 48,000 baud. Because the drone and rover share a base station module, the data-rate and air-rate of the rover dGPS module's wireless link must be increased accordingly. This should be done by attaching the board to a computer via a serial cable and reconfiguring the radio using AT commands.